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# Investigation of the effects of steam injection on performance and emissions of a diesel engine fuelled with tobacco seed oil methyl ester

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ABSTRACT

Although biodiesel is renewable, nontoxic, biodegradable and has low emission profiles, the main drawback of using biodiesel in diesel engines is higher $NO_x$. In this study, steam injection has been used as a method to reduce $NO_x$ emissions of a direct injection diesel engine fuelled with tobacco seed oil methyl ester (TSOME). The effects of 10% (S10) and 20% (S20) steam ratio have been investigated in terms of performance and emissions of a diesel engine fuelled with 20% (B20) TSOME. Steam is injected into the inlet manifold during inlet period. It is shown that steam injection into the engine fuelled with B20 fuel improved torque, effective power, effective efficiency and specific fuel consumption (SFC) decreased. Whilst S10 has been found optimum at the low engine speeds, S20 is optimum at the high speeds for the performance. However, S10 has been found as optimum for the exhaust emissions. At this injection ratio, both $NO_x$ and smoke emissions decrease. As a result, steam injection is a found powerful tool for reducing $NO_x$ emissions of the diesel engines running with biodiesel blend.



## 1. Introduction

Biofuels and their blends with fossil fuel that production and application have been commonly increased internationally have become significant energy resources over the last couple of decades [1,2]. Fatty acid methyl esters (FAME) appear to be the most popular as a potential alternative fuel for compression ignition engines [3–5]. It is the most suitable fuel in environmentally sensitive areas where environmental conditions must meet high standards [6,7]. The substitution of conventional diesel fuels with rapeseed oil methyl esters comprises already a commercial activity in many European countries. There are a lot of studies investigating the effects of engine performance and emission characteristics using different biodiesel blends [5–12]. However, the main drawback of the engines fuelled with biodiesel blends is $NO_x$ emission.

Nowadays, water injection methods to reduce $NO_x$ emissions have been promising methods which can accomplish both of these goals [13–15]. Four major practical means for introducing water into the combustion chamber have been reported in the literature: Fumigating water into the engine intake air, direct injection into the engine through separate injectors, in-line mixing of water and fuel and mixtures of stabilized fuel and water emulsions. Some researchers [8–10,16] have shown in their studies that it is possible to reduce NOx and smoke with no loss of power and efficiency by means of introducing water into the combustion chamber. Among the researchers, Tsukahara et al. [16] showed reduction of specific fuel consumption (SFC) could be possible with water emulsified diesel. Tsukahara et al. [16] explained the reason of improvements in SFC with the following main reasons: Formation of a finer spray due to rapid evaporation of water, more air entrained in the spray due to increasing momentum and penetrating force, suppression of thermal dissociation and decreasing in cooling loss due to a lower flame.

However, these methods mentioned above have some advantages and drawbacks. Emulsified fuel–water blends can be used as an alternative method and have been shown to reduce $NO_x$ and particulate matter (PM) emissions. However, emulsified fuel blends tend to lower the combustion temperature indiscriminately. Lower temperatures too early in combustion can lead to increased ignition delay and engine noise. A more significant drawback to emulsified fuels is that the percentage of water is constant and cannot be changed for cold start or other transient operating conditions [11,17].

The fumigation technique has been shown to reduce $NO_x$ emissions in DI diesel engines. However, some drawbacks have arisen. One of the drawbacks of this method is to require about twice amount of the liquid volume for the same reduction in $NO_x$ when compared to DW injection. Another drawback is that water can contaminate with the oil and increase engine wear and condensing water in the manifold can increase corrosion side effects [8]. Corrosive side effects of water and stabilizing agent on metallic parts of an engine are

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not yet solved in the techniques of fumigation and emulsified fuel [8,13–15,17].

Direct water (DW) injection method has the advantage over fumigation and emulsified fuel as the liquid water is injected close to the flame and away from the wall [13]. DW injection allows the fuel–water ratio to be changed for cold start or different operating conditions unlike emulsified fuels. The water would have to be injected into the hot reaction zone inside the cylinder. This would require considerable injection distances for the water spray which can be hardly achieved [12].

Another method for controlling $NO_x$ emissions is named as Electronic Controlled Steam Injection (ESI) system developed by Parlak et al. [17–20]. From the literature reviews, water injection inside the diesel engine has certain effects to reduce emissions and improve performance parameters. But, the water inside the cylinder causes corrosion. Steam injection is the preferred method recently, so as to reduce this negative effect in the internal combustion engines [17–20].

In the studies conducted by Parlak at al. optimum steam ratio was found as 20% in terms of performance and emission reduction. At full load conditions, it was found that effective power increased about 2.5%, specific fuel consumption (SFC) decreased to 5% especially in low speeds. The $NO_x$ emissions decreased up to 33% [17–19].

The main drawback of the engine fuelled with biodiesel is higher $NO_x$ emissions. Hence, it is important to eliminate these pollutant emissions during operations. In the literature, there is no study investigating the effects of steam injection on engine performance and $NO_x$ emissions fuelled with biodiesel. This study investigates the effects of steam injection on $NO_x$ emissions and engine performance of the engine fuelled with tobacco seed oil methyl ester.

## 2. Material and methods

### 2.1. Determination of fatty acid composition

Fatty acid composition of tobacco seed oil was determined by means of GC (gas chromatography) analysis. A Hewlett Packard 5890 series II Gas Chromatograph, with a split–splitless injector and SP2340 type column 30 m long was used. Film thickness was 1.0 μm and the inside diameter was 0.53 mm. Also, the detector was a FID. An automatic sampler was attached to the HP 5890 GC to automate sample introduction. The sample (tobacco seed oil) injection amount was 0.5 mL/min. The temperature of the GC injector was 250 °C. Helium was used as a carrier gas. The split ratio was 1:50. The flame ionization detector temperature was 260 °C. The oven temperature was kept at 150 °C for 3 min. Afterwards, the oven was heated with heat ratio 10 °C/min to 225 °C. The oven temperature was constant for 15 min. The fatty acids of tobacco seed oil were identified and quantified using the AOAC 963.33 and AOAC963.22 methods. Gas chromatogram of tobacco seed oil (TSO), fatty acid composition of TSO and chemical formulas are shown in Fig. 1 and Table 1, respectively [21].

As can be seen from Table 1, the total saturated and unsaturated fatty acids inside the tobacco seed oil have been found to be 11.92% and 87.96% respectively. Whilst palmitic acid was most abundant (8.72%) amongst saturated fatty acids (Table 1), the major parts of unsaturated fatty acids were linoleic acid (75.58%) and oleic acid (11.24%). As reported in the present work, the amounts of unsaturated and saturated fatty acids are close to those reported by Giannelos et al. [22] (85.2% and14.8%), Mukhtar et al. [23] (87.36% and 12.64%) and Baydar et al. [24] (84.35% and 12.53%) [21]. The slight difference in the amounts of different fatty acids could be because of different species of tobacco (Nicotiana) used in the studies or different environmental or geographical conditions [21].

### 2.2. Production of TSOME

The tobacco plant is grown in 119 countries all over the world [25,26]. The leaves of the plant have been used in the production of cigarettes in the tobacco processing industries and are a commercial product. Hence, statistical information on tobacco harvesting area and leaf production is handily obtainable [25,26].

Tobacco seeds are a by-product of tobacco leaf production. Due to the fact that tobacco seed oil is a non-edible oil, it is not used as a commercial product in the food industry. Most of them are left unused in the fields, only a small amount of tobacco seeds have been collected from fields for next year production. [26].

To produce biodiesel, heterogeneous catalysts are stipulating for the transesterification reaction of vegetable oils [27]. Transesterification method was used for producing tobacco seed oil methyl ester (TSOME). The weight of the oil, alcohol and catalyst was measured by 0.0001 g sensitivity. Base catalyst was chosen because free fatty acid was found around 1% in the oil analyses. Reaction temperature, alcohol/oil molar rate, type and amount of catalyst, and reaction duration were chosen as parameters to find out the optimum conditions of reaction for TSO.

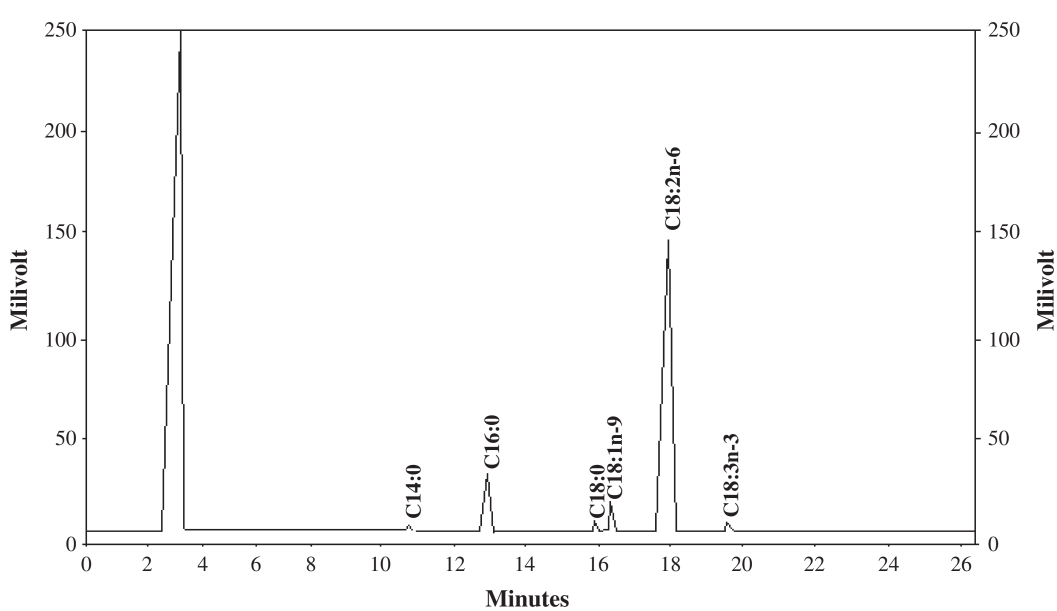


**Fig. 1.** Gas chromatogram of TSO [19].

**Table 1**
Fatty acid composition of tobacco seed oil [21–24,28].

| Fatty acids | Chemical structure [22] | Present study | Ref. [22] | Ref. [28] | Ref. [24] | Ref. [23] |
|---|---|---|---|---|---|---|
| | | % | % | % | % | % |
| Myristic acid (C14:0) | $CH_3(CH_2)_{12}COOH$ | 0.14 | 0.09 | – | 0.17 | 1.13 |
| Palmitic acid (C16:0) | $CH_3(CH_2)_{14}COOH$ | 8.46 | 10.96 | 8.82 | 8.87 | 8.72 |
| Stearic acid (18:0) | $CH_3(CH_2)_{16}COOH$ | 3.38 | 3.34 | – | 3.49 | 2.64 |
| Oleic acid (C18:1) | $CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$ | 11.24 | 14.54 | 13.72 | 12.4 | 13.46 |
| Linoleic acid (C18:2) | $CH_3(CH_2)_3(CH_2CH{=}CH)_2(CH_2)_7COOH$ | 75.58 | 69.49 | 75.30 | 67.75 | 71.63 |
| Linolenic (C18:3) | $CH_3(CH_2CH{=}CH)_3(CH_2)_7COOH$ | 1.14 | 0.69 | 1.59 | 4.20 | 0.93 |
| Acid value | | %1.0 | – | – | – | – |

Methyl alcohol in 99% purity was used for the transesterification process. Measured and premixed methyl alcohol and catalyst (NaOH) mixture was poured on a glass beaker, and then the catalyst was stirred until all catalysts completely resolved with alcohol. After the TSO was heated up to the desired temperature, the prepared alcohol–catalyst mixture was added to TSO oil to start the transesterification reaction by using the heating bath and a glass balloon of Buchi rotary evaporator. The temperature sensitivity of the heating bath was ± 0.1 °C. 100 g of the TSO sample was used. The mixture was stirred for 1 h at 600 rpm with ±1 rpm sensitivity, and then it was taken into the separating funnel and waited until ester-glycerin separation was taken place.

It was necessary to clean the TSOME by sterile purified water to separate the remaining glycerin, mono- and di-glycerides. Hot sterile purified water was added to the TSOME in the separating funnel for the cleaning process, then the separating funnel was shaken upside down by repeating 4 times. After this process, the TSOME–water mixture was left to settle for 12 h and then pure water and glycerin glimmers were removed from the separating funnel. After all these stages, the remaining TSOME was separated from all of the unwanted particles by using a centrifuge separating device called NUVE NF400 in 4000 rpm and 3600 RCF for 30 min. Finally, the TSOME sample was dried by heating up to 110 °C for 60 min. The TSOME sample produced with the conditions of 1/5 oil–alcohol ratio, 50 °C reaction temperature and 0.5% NaOH catalyst was analyzed at TUBİTAK Marmara Research Centre. The analysis results are given in Table 4.

### 2.3. Engine setup

The experiment was conducted on a single cylinder, naturally aspirated, four-stroke, and water cooled, direct injection diesel engine.

**Table 2**
Specification of the test engine.

| Engine type | Super Star |
|---|---|
| Bore [mm] | 108 |
| Stroke [mm] | 100 |
| Cylinder number | 1 |
| Stroke volume [l] | 0.92 |
| Power −1500 rpm, [kW] | 14.7 |
| Injection pressure, [bar] | 175 |
| Injection advance, [CA bTDC] | 35 |
| Maximum speed, [rpm] | 2500 |
| Cooling type | Water |
| Injection type | DI |

**Table 3**
The errors in parameters and total uncertainties.

| Parameters | Systematic errors, ± |
|---|---|
| Load, N | 0.1 |
| Speed, rpm | 1.0 |
| Time, s | 0.1 |
| Temperature, °C | 1.0 |
| Fuel consumption, g | 0.1 |
| $NO_x$, ppm | 5% of measured value |
| CO, % | 5% of measured value |
| HC, ppm | 5% of measured value |
| Smoke density | %1 |
| | Total uncertainty, % |
| Specific fuel consumption | 1.5 |
| Torque, Nm | 1.1 |

Fig. 2 shows the experimental setup and the specifications of the engine are given in Table 2. In order to measure torque, the engine was coupled with a hydraulic dynamometer of 50 kW absorbing capacity using a load cell with the precision of 0.1 N. Full load tests were conducted at the engine speeds of 1200, 1400, 1600, 1800, 2000, 2200 and 2400 rpm. Fuel consumption was measured by an electronically controlled balance with the precision of ±0.1 g. The average and instant fuel consumption was directly transferred to a PC via RS-232 serial port.

$NO_x$, CO and HC emissions were measured with MRU Spectra 1600 L gas analyser. Special emphasis was given to the measurement error for pollutant emissions. Smoke density was measured at full load conditions. To ensure the accuracy of the measured values, the gas analyser was calibrated before measurement using reference gases. The smoke metre was also set to zero point before each measurement. The errors in parameters measured and total uncertainties are given in Table 3.

### 2.4. Electronic controlled steam injection system

The system was composed of a rail, solenoid type injector, electronic control unit and an absolute encoder. The encoder gave a reference pulse signal (5 V) to determine the engine top dead center (TDC). The TDC sign on the flywheel of the test engine was matched with the reference output of the encoder by using digital oscilloscope

**Table 4**
The analysis results of TSOME according to EN14214.

| | Method | NaOH |
|---|---|---|
| Ester content, %(m/m) | EN14103 | 97.0 |
| Carbon residue, %(m/m) | ENISO10370 | 0.17 |
| Copper band corrosion (3 h at 50 °C) | ENISO2160 | 1.0 |
| Cold filter plug point, °C | EN116 | −10.0 |
| Water content, mg/kg | ENISO12937 | 400.0 |
| Total contamination, mg/kg | EN12662 | 23.0 |
| Iodine value, g iodine/100 g | EN1411 | 118.0 |
| Methanol content, %(m/m) | EN1410 | 0.18 |
| Triglyceride content, %(m/m) | EN1410 | 0.11 |
| Diglyceride content, %(m/m) | EN1410 | 0.05 |
| Total glycerol, %(m/m) | EN1410 | 0.02 |
| Phosphorus, mg/kg | EN14107 | 4.0 |
| Monoglyceride content, %(m/m) | EN14105 | 0.29 |
| Density, g/cm$^3$, 15 °C | EN ISO 3675 | 0.86 |
| Cetan number | ISO 3104 | 49.0 |
| Lower heat value, MJ/kg | DIN 51900-1 | 40.02 |
| Sulphur, mg/kg | EN ISO 20846 | 0.0 |
| Viscosity, mm$^2$/s | EN ISO 3104 | 3.5 |
| Pour point, °C | ASTM D97 | −12.0 |
| Flash point, °C | ASTM D93 | 152 |

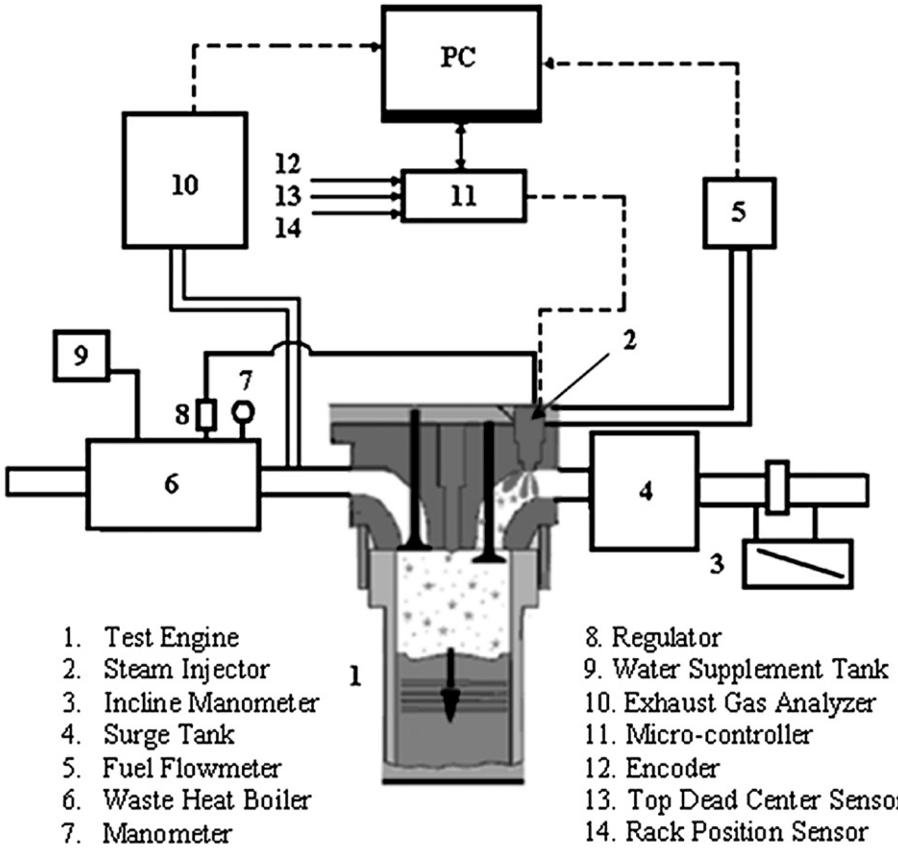


**Fig. 2.** Test setup.

before testing. To obtain the exact starting time of injector, the opening delay was determined. For this, the signal width applied to the injector was shortened until the injection failed. Fig. 3 shows the amount of steam depending on the signal duration applied to the injector coils. As can be seen from the figure, injection begins only after the delay (response time). Required crank angles for 20% steam ratio (S20) were calculated for all the engine speeds tested as shown in Fig. 4. A MATLAB code was developed to control the injection ratio [18].

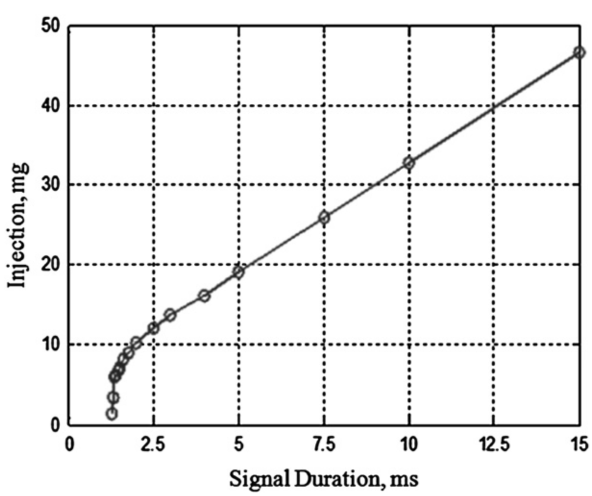


**Fig. 3.** Variations of the amount of injected steam depending on the signal times.

## 3. Results and discussion

### 3.1. Determination of steam injection limit

To protect the risk of corrosive effects due to condensation of steam on metallic surfaces at cold weathers, the amounts of steam

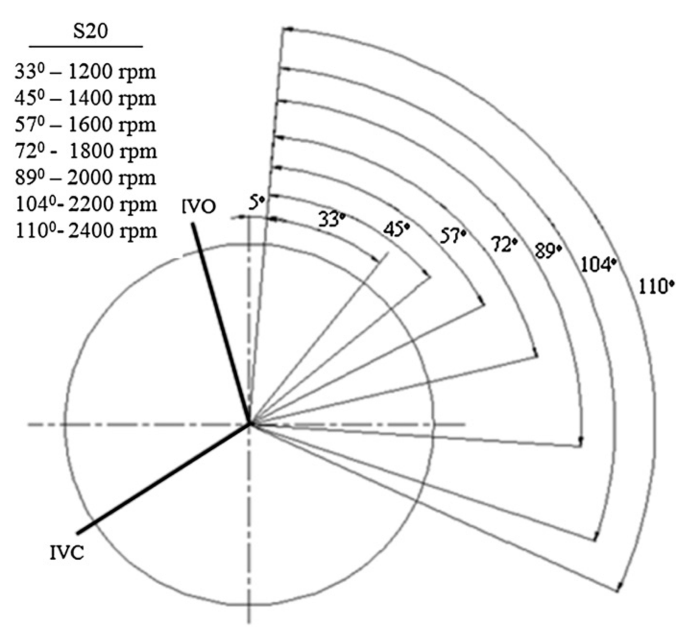


**Fig. 4.** Required crank angles for 20% steam injection for various engine speeds at full load conditions.

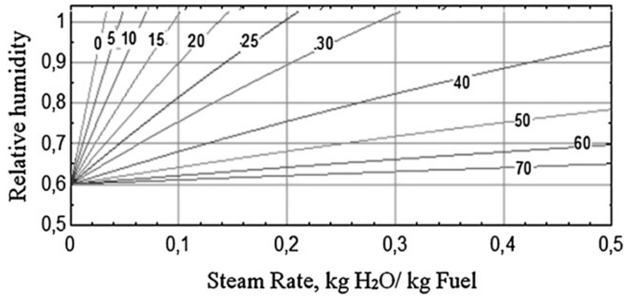


**Fig. 5.** The amounts of steam limits for various saturation temperatures at 3 bar.

injection considering saturation temperature have been calculated for the whole engine cycle. Inlet period of the engine is found critical in steam condensation aspect. For overcoming the condensation problem, water in the heat exchanger is heated up to 133 °C temperature and 300 kPa pressure conditions via exhaust gas energy and kept in a rail at these conditions. During the water injection periods through the injector, the heated water in the rail changes its phase from the compressed liquid conditions at 300 kPa and 133 °C to superheated vapor conditions at 101.325 kPa and inlet temperature. Fig. 5 shows the required amounts of steam to be injected depending on the intake air temperatures at standard atmosphere pressure. As can be seen from the figure, the amount of steam injected into the cylinder increases with the increase of inlet temperature [18,19].

### 3.2. The effects of steam injection on engine performance

The effects of steam injection on torque and effective power and specific fuel consumption values of the engine fuelled with 20% TSOME (B20) during inlet period can be seen in Figs. 6, 7 and 8, respectively. As can be seen from the figures, there are significant improvements in the torque, effective power and SFC of the engine fuelled with S20 for all the engine speed ranges. Whilst maximum increased in the torque and effective power reach up to 2.0% at 1800 rpm.

Since 20% TSOME blend (B20) gives the best results in all the ranges of engine speeds at full load condition in terms of performance, steam injection tests have been conducted with the engine fuelled with B20 blend. Torque and effective power increase in cases of steam injection for B20 blend. The reason of higher torque and the effective power compared to pure diesel operation is that B20

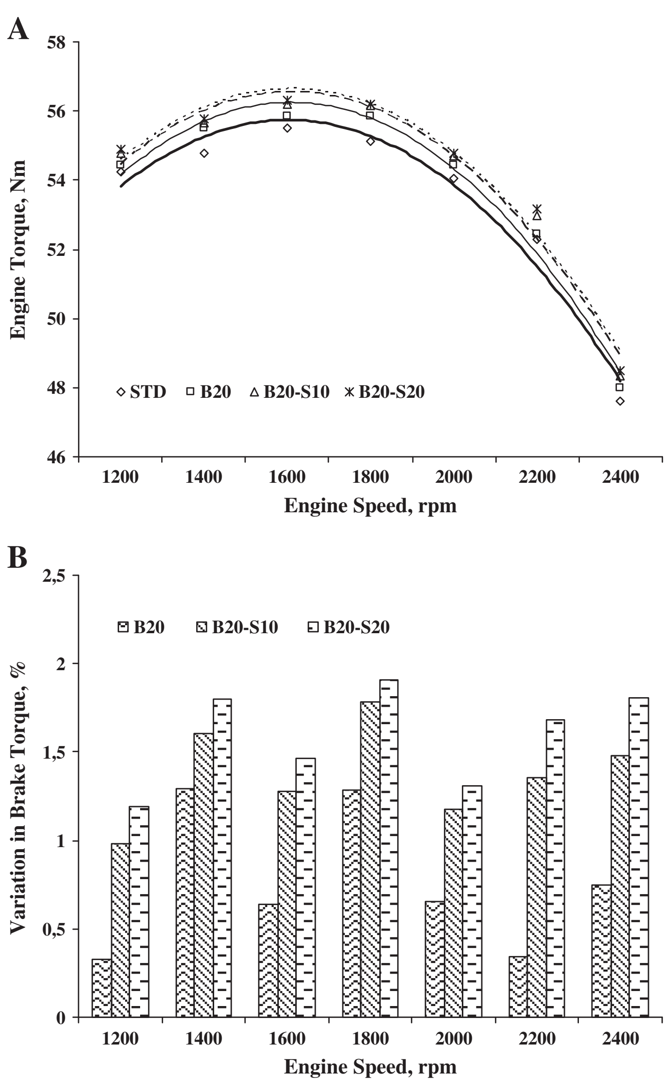


**Fig. 6.** A. The effects of steam injection on diesel fuel and TSOME blend on engine torque. B. Variations of engine torques for different fuels and steam ratios.

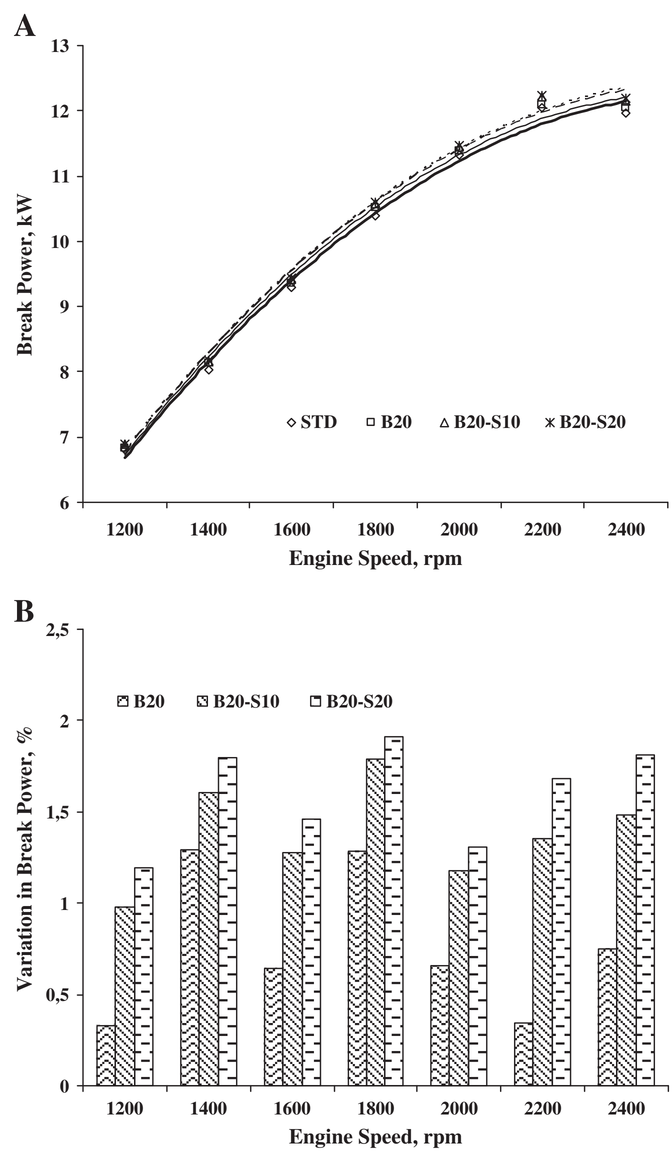


**Fig. 7.** A. The effects of steam injection on diesel fuel and TSOME blend on effective power. B. Variations of effective power for different fuels and steam ratios.

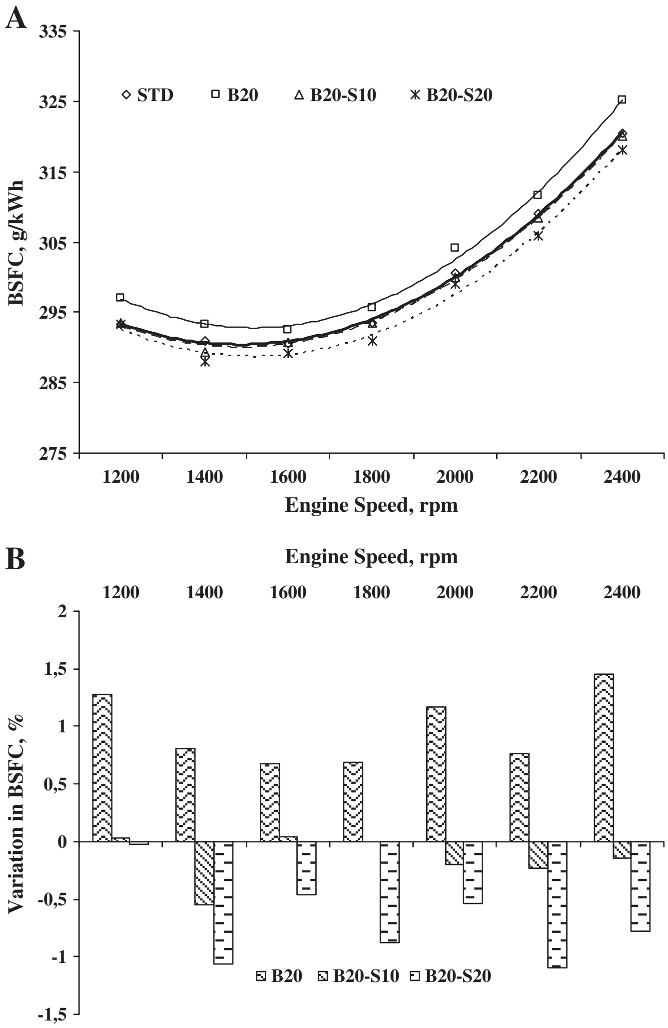


**Fig. 8.** A. The effects of steam injection for diesel fuel and TSOME blend on SFC. B. Variations of SFC for different fuels and steam ratios.

blend has higher density compared to pure diesel fuel. Since the heating value of the injected B20 blend per stroke from the pump plunger to the engine is higher, the torque and effective power increase more than the standard diesel engine.

The effects of steam injection during intake period on specific fuel consumption (SFC) can be seen in Fig. 8. More fuel per cycle from the fuel pump plunger into the engine is injected as density of the B20 blend is higher than diesel fuel to compensate for effective power decrease since B20 has a lower heating value compared to that of pure diesel fuel. Thus, SFC increases in the case of B20 blend compared to that of standard diesel engine. However, when steam injection is performed on the engine fuelled with B20 blend, the SFC of the engine together with brake power and effective power also improves. The decrease in SFC is found 1.2% at 1400 rpm and 2200 rpm. Suppression of thermal dissociation may be another reason of improvement as explained by Tsukahara et al. [16].

Effects of steam injection on engine effective efficiency can be seen in Fig. 9. Effective efficiency increases in the case of steam injection to the engine. Best results are obtained with B20–S20 condition. Maximum increase in the effective efficiency reaches up to 2.7% at 1400 rpm at this condition.

The improvement in performance parameters can be explained by three reasons. One of them is that the steam was sent into the engine under 3 bar pressure and 133.5 °C temperature caused to increase inlet enthalpy of the engine in comparison to B20 blend. Another reason is that the injected finer water droplets inside the cylinder in contact with fuel causes a very small surface stress. Thus, the fuel in the cylinder is divided into much more small droplets leading to improved fuel–air mixing owing to increased surface and better atomization with micro explosions. All these effects cause increase in engine combustion efficiency and thus increase in torque and effective power and decrease in SFC. Best results in the performance parameters are obtained at B20 and 20% steam ratio (B20–S20). The engine torque and effective power increase from 1.2% to 1.8% between 1200 rpm and 2400 rpm.

### 3.3. Exhaust emissions

#### 3.3.1. $NO_x$ emissions

The interest in water injection techniques derives from the fact that water in the form of micrometer sized droplets exerts some positive effects on the combustion of the fuel and exhaust emissions, mainly $NO_x$. Using steam in diesel engines causes to reduce $NO_x$ and improves the combustion efficiency. The finely atomized water droplets vaporize immediately after being injected into the combustion chamber. The combined effect of vaporization absorbing heat, relatively high molar heat capacity of water and reduced partial pressure of oxygen brings down the peak combustion temperature and hence lowers the nitrogen oxide formation [20–22]. Fig. 10 shows the effect of steam injection on $NO_x$ emissions.

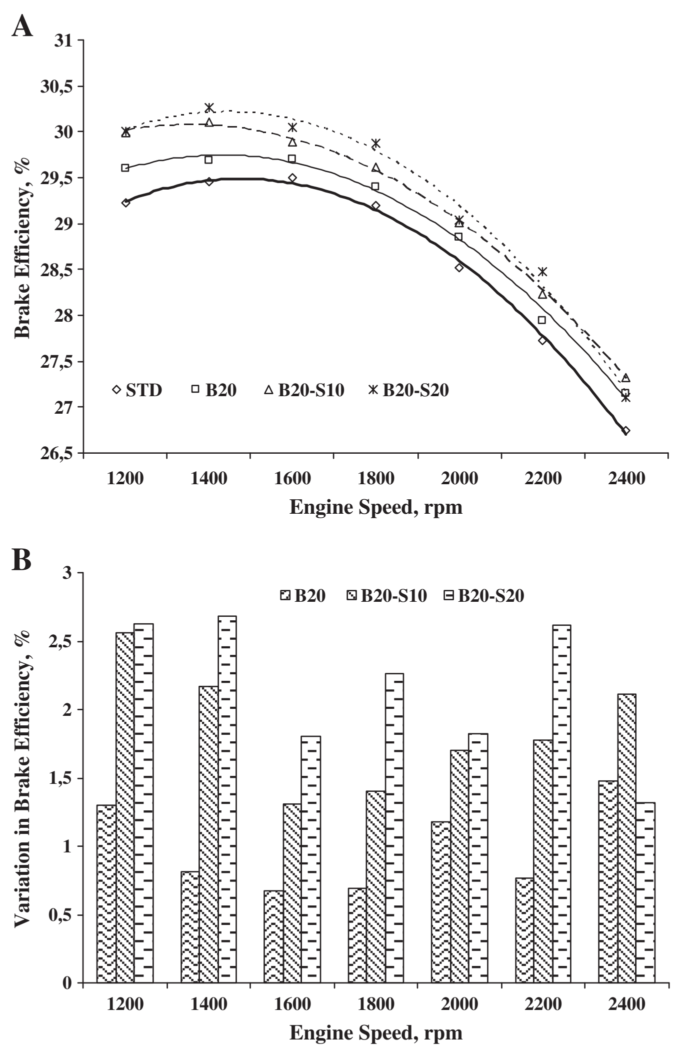


**Fig. 9.** A. The effects of steam injection for diesel fuel and TSOME blend on effective efficiency. B. Variations of effective efficiency for different fuels and steam ratios.

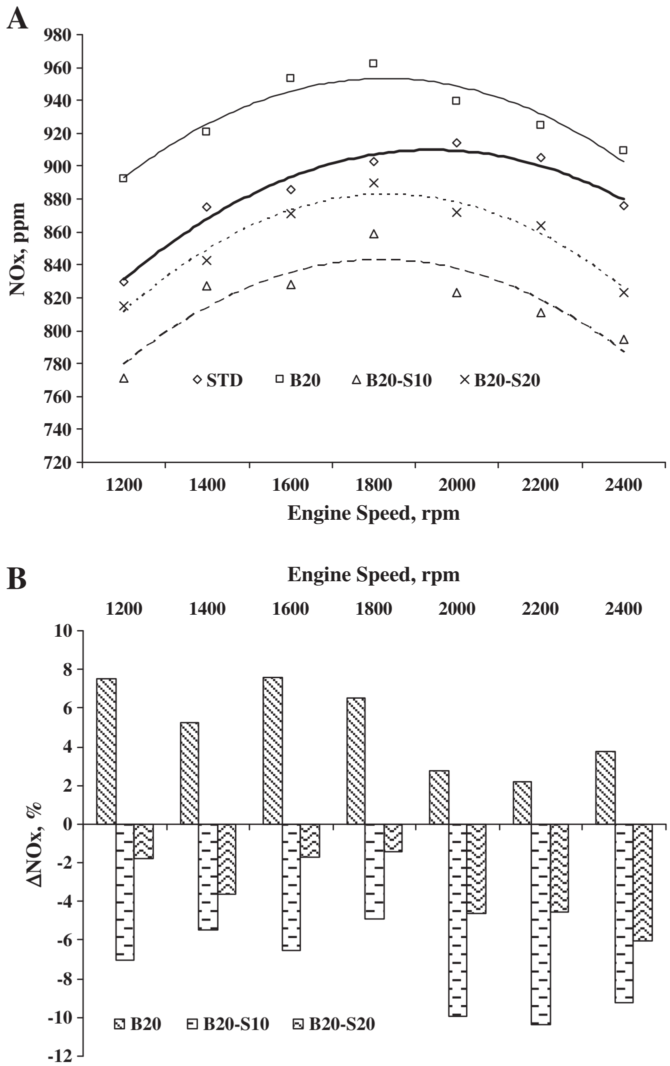


Fig. 10. A. The effects of steam injection for diesel fuel and TSOME blend on $NO_x$ emissions. B. Variations of $NO_x$ emissions for different fuels and steam ratios.

As can be seen from the figure, $NO_x$ emissions of the engine fuelled with B20 blend considerably decrease with all over the engine speeds in the case of using 10% and 20% steam ratios. The maximum decrease in $NO_x$ emissions is obtained at 10% steam ratio for the B20 blend. In this steam ratio, $NO_x$ emissions have better 10% on average at all engine rpm in the case of fuelled with B20 in comparison to diesel oil. Although $NO_x$ emissions of the engine using B20 blend increase 6% on average in comparison to diesel oil, steam injection into the engine fuelled with B20 is eliminated. As a result of steam injection, $NO_x$ is 9% better on average in the case of using B20 in comparison to using standard diesel oil.

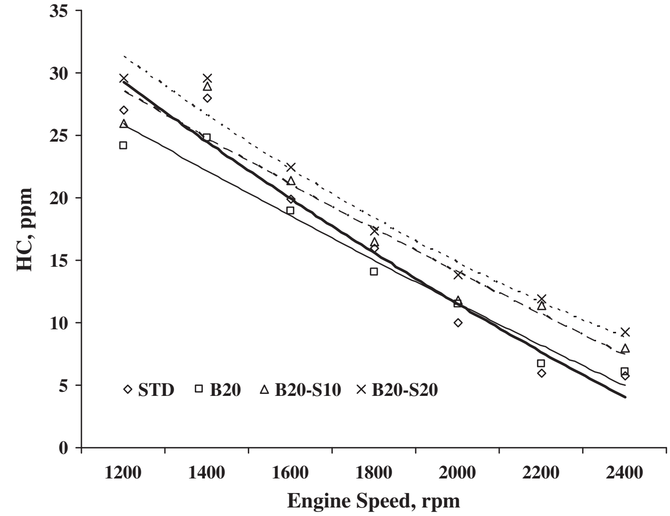


Fig. 12. The effects of steam injection on HC emissions for diesel fuel and TSOME blend.

### 3.3.2. Carbon monoxide (CO) emissions

CO emission values that measured at full load condition can be seen in Fig. 11 in the case of injection steam at different ratios and using B20 fuel. Steam injection reduces maximum flame temperature that reached at the end of the combustion. Accordingly, CO emissions slightly increase in the case of steam injection. CO considerably decreases at low and moderate speeds for the B20 fuelled diesel engines as it includes 10% oxygen in its chemical formula. However, CO emissions slightly increase in the steam injected and B20 fuelled diesel engines. CO emissions begin to decrease after moderate speeds in the case of steam injection. This situation shows that CO emissions of the engine fuelled with B20 blend is positively affected by the steam injection.

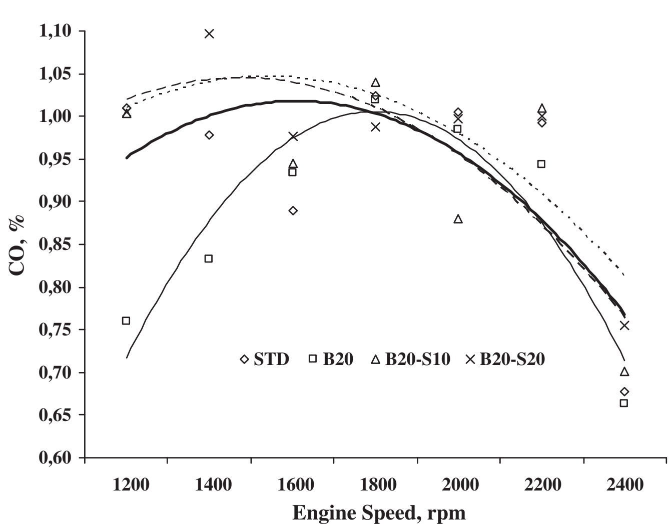


Fig. 11. The effects of steam injection for diesel fuel and TSOME blend on CO emissions.

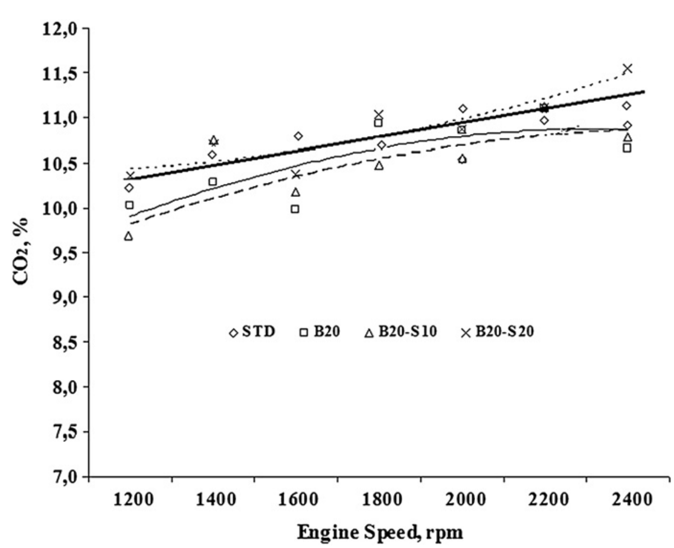


Fig. 13. The effects of steam injection for diesel fuel and TSOME blend on $CO_2$ emissions.

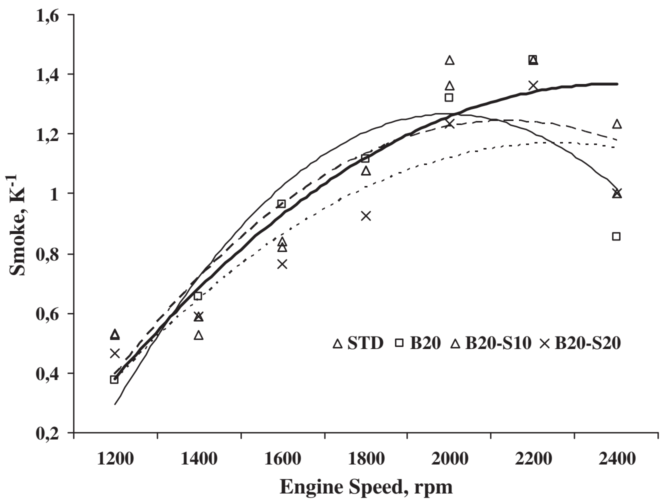


**Fig. 14.** The effects of steam injection for diesel fuel and TSOME blend on smoke emissions.

*3.3.3. Unburnt hydrocarbon emissions*

Fig. 12 shows the effects of steam injection on HC emissions for diesel fuel and 20% TSOME blend at full load conditions. As can be seen from the figure, whilst HC emissions decrease with B20 fuelled diesel engine, the emissions slightly increase in the case of steam injected diesel engines with B20. However, it is seen that the changes in the emission values of standard and steam injected diesel engines are within the limits of uncertainty when considering measurement accuracy.

*3.3.4. $CO_2$ emissions*

Fig. 13 compares the effects of steam injection on $CO_2$ emissions of B20 fuelled diesel engine with the standard one. The $CO_2$ emissions generally reduce with B20 fuelled diesel engine and steam injected diesel engine fuelled with B20 blend at all the engine speeds. $CO_2$ emissions reduce depending on the reduction of SFC of steam injected diesel engines fuelled with B20 reduced. The reason of reduction of B20 fuelled diesel engine is that TSOME includes 10% oxygen in its chemical structure. The minimum $CO_2$ emission is 9.6% at 1200 rpm with B20 and S10 condition.

*3.3.5. Smoke emissions*

Smoke emission values that are measured at full load condition in case of steam injection at different ratios and using B20 fuel are seen in Fig. 14. Smoke emissions show reduction trend when using steam injected and B20 fuelled diesel engine operation modes. Maximum smoke reduction rate is observed with B20 fuelled diesel engine at 2400 rpm. Smoke emissions reduce from 1.1 $K^{-1}$ to 0.8 $K^{-1}$. The study shows that although $NO_x$ emissions reduce with the steam injection, smoke emission is not affected by temperature reduction in the cylinder. This shows that steam injection improves combustion efficiency leading to decrease both $NO_x$ emissions and smoke emissions in the case of B20 fuel performance and emission characteristics together.

## 4. Conclusion

In this study, the effects of steam injection on performance and exhaust emissions of a single cylinder diesel engines fuelled with B20 have been experimentally investigated. TSOME blend was prepared on a molar base. The results showed that the effective power and the torque increased with B20. However, on the contrary, TSOME blend caused to increase about 6% $NO_x$ emissions as TSOME contains nearly 10% oxygen in the content.

All the performance parameters of the engine running with B20 have been improved in the case of steam injection. Optimal steam ratio has been found as 20% in terms of performance and pollutant emissions [17–20]. When steam injection is applied to the engine fuelled with B20, $NO_x$ emissions decrease about 10% in an average base in all over the engine speeds. Although smoke emissions reduced, small amounts of increases of HC and CO emissions have been observed.

As a conclusion, electronic controlled steam injection system is found a powerful tool for reducing $NO_x$ emissions and also improving performance of the diesel engines fuelled with TSOME blend.

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